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PHYSICAL AND METALLOGRAPHIC PROPERTIES OF COPPER-ZINC-ALUMINUM ALLOYS CONTAINING SMALL AMOUNTS OF MAGNESIUM

Air Service Information Circular, Volume IV, No. 393

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PHYSICAL AND METALLOGRAPHIC PROPERTIES OF COPPER-ZINC-ALUMINUM ALLOYS CONTAINING SMALL AMOUNTS OF MAGNESIUM

(MATERIAL SECTION REPORT)

▽

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McCook Field, Dayton, Ohio
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PHYSICAL AND METALLOGRAPHIC PROPERTIES OF COPPER-ZINC-ALUMINUM ALLOYS CONTAINING SMALL AMOUNTS OF MAGNESIUM.

PURPOSE.

To determine the effect of replacing iron in aluminum alloy No. 3, Specification No. 11,019, by small amounts of magnesium.

CONCLUSIONS.

The use of magnesium in place of iron in aluminum alloy No. 3 is not advisable. An equal tensile strength in the "as cast" condition may be obtained with the addition of from 0.25 to 1 per cent magnesium in place of the iron, but the ductility, as measured by the percentage of elongation, is from 50 to 65 per cent lower. The hardness values are appreciably higher.

The best results were obtained with 0.5 per cent added magnesium, while with over 1 per cent, both the tensile strength and elongation fall off very rapidly.

A comparison of the effects of 0.5 per cent magnesium and 1 per cent of added iron on the average physical properties follows:

Composition.					Tensile strength (pounds per square inch).	Elongation in 2 inches (per cent)	Brinell hardness 500 kg./10 mm. ball.
Cu.	Zn.	Mg.	Fe.	Al.			
2.00	10.00	0.50	....	87.50	27,330	1.4	65.0
[1]2.00	10.00	....	1.00	87.00	[2]28,140	8.8	52.4
					[3]26,000	5.0	

[1] Composition used at McCook Field for aluminum alloy No. 3.
[2] McCook Field Report, Serial No. 1731.
[3] Routine average.

The tensile strength and hardness of the alloys in the magnesium-zinc series may be increased at the expense of the elongation by suitable heat treatment, but due to their low ductility and higher specific gravity they are inferior to the alloys of the duralumin type.

The following physical properties were obtained from aluminum alloy No. 3 with 0.5 per cent magnesium in place of iron:

Tensile strength, pounds per square inch	35,680.00
Elongation in 2 inches, per cent	0.83
Brinell	80.00

The following metallographic constituents were observed in the alloys of this series:

A. Mg_2Si.
B. Al_2Mg_3–Al eutectic.
C. $CuAl_2$–Al eutectic.
D. Slate gray constituent, with purple tinge, which resembles constituent having the same color in the silicon-aluminum series. It is thought to be a compound of iron, silicon, and possibly of aluminum.
E. Needles of a similarly colored constituent considered $FeAl_3$.
F. In the furnace-cooled specimens a finely divided precipitate indentical in color to Al_2Mg_3.

MATERIAL.

The alloys used in this investigation were made in the material section foundry. The foundry melt numbers and chemical compositions of the raw materials used in their manufacture are as follows:

Material.	Melt No.	Chemical analysis.						
		Cu.	Si.	Fe.	Al.	Pb.	Cd.	Zn.
Aluminum ingot	523	0.07	0.20	0.35	90.48	......	......	......
Zinc ingot	543	......	......	0.40	......	0.22	0.50	99.24
Magnesium	919	Commercially pure stick				......	......	......
Copper-aluminum hardener	1307	46.21	0.21	0.42	53.17	......	......	......

PROCEDURE.

The following alloys were made in melts of 30 pounds each:

Alloy symbol.	Melt No.	Composition as mixed.			
		Mg.	Cu.	Zn.	Al.
M-¼	1428	0.25	2.00	10.00	87.75
M-½	1434	.50	2.00	10.00	87.50
M-1	1438	1.00	2.00	10.00	87.00
M-2	1447	2.00	2.00	10.00	86.00
M-3	1453	3.00	2.00	10.00	85.00

The aluminum ingot and copper-aluminum hardener were charged together in a No. 30 plumbago crucible. The charge was melted in a gas-fired furnace. The maximum temperature was held between 1,300° and 1,350° F. The zinc was then introduced in the solid form and the pot drawn from the furnace, after which stick magnesium was introduced by holding beneath the surface of the molten metal until dissolved. No trouble was experienced from the magnesium igniting as long as the latter operation was performed quickly. The pouring temperature ranged from 1,270° to 1,300° F., the temperatures being recorded both in and out of the furnace with a chromel-alumel thermocouple (without protecting tube) in conjunction with a Hoskins high-resistance millivolt meter.

The following test specimens were poured in green sand from each melt:

Nine molds tension specimens (as cast), type TB-1.
Three porosity cups, type PC-2.
Three shrinkage bars.
One hot shortness test bar.

In addition to the above, 11 molds of tension specimens (as cast), type TB-1, were cast from each of the above melts from the gates and risers. The melt numbers corresponding to the different compositions are listed below:

Alloy symbol.	Melt No.
M-¼	1453
M-½	1436
M-1	1440
M-2	1449
M-3	1453

EXPLORATORY MELTS.

The gates and risers were further used to make up the following exploratory melts. Four molds of tension specimens (as cast), type TB-1, were cast from each of these alloys:

Alloy symbol.	Melt No.	Composition as mixed.					
		Mg.	Cu.	Zn.	Al.	Si.	Te.
M-4½	1455	4.50	2.00	10.00	83.50	....	....
M.5-S.5	1472	.50	2.00	10.00	87.00	0.50	....
M2-S4	1456	2.00	2.00	10.00	82.00	4.00	....
M3-T2	1460	3.00	2.00	10.00	83.00	....	2.00

HEAT TREATMENT.

Tension specimens from the remelted and exploratory alloys were heat treated as follows:

Heat treatment symbol.	Number of bars.	Annealing temperature.	Quench.	Aging.
E	3	3 hours at 920° F.	Furnace cooled.	Room temperature.
F	3	do	H_2O, 70° F.	Do.
G	3	do	H_2O, 212° F.	3 hours at 212° F.

Test bars in the "as cast" condition were set aside to age one month, six months, one year, two years, three years, and four years.

PHYSICAL TESTS.

The standard practice was observed in making tension tests and hardness and specific gravity determinations. Six bars from each of the original melts and three bars from the remelts and exploratory melts were pulled within 48 hours after casting. Heat treated and aged specimens were pulled "as cast." Three bars from each of the original melts were machined in order to determine the "skin effect." Test bars from melts 1428, 1434, and 1438 were threaded and pulled in self-aligning adapters at 200°, 400°, and 600° F.

SHRINKAGE AND HOT SHORTNESS TESTS.

The method of making the shrinkage determinations and hot shortness test is outlined in Material Section Report No. 178, Serial No. 1964, A. S. Information Circular Vol. IV, No. 385.

POROSITY TEST.

The method of making this test is described in Material Section Report No. 160, Serial No. 1882.

CHEMICAL ANALYSES.

The original melts were analyzed for copper, iron, zinc, and silicon, and the aluminum taken as the difference.

METALLOGRAPHIC.

Metallographic specimens were taken from the riser end of the middle test bar in all cases. Specimens of the original melts, remelts, and heat-treated material were examined.

RESULTS.

The results of the tension tests, hardness and specific gravity determinations, and shrinkage tests are summarized in Table 1 and shown graphically in Figures 1, 2, and 3.

The results of the tests at elevated temperatures are shown in Figures 4 and 5.

The alloys of this series give somewhat erratic porosity results, ranging from 81 sec. per 1,000 cubic centimeters to 2,600 sec. per 1,000 cubic centimeters. The results were in no way consistent with the different compositions, but taking the alloys in the useful range, the results are considerably below those obtained in the iron-copper-zinc series.

CHEMICAL ANALYSES.

The results of chemical analyses are shown in Table 2.

METALLOGRAPHIC EXAMINATION.

The average structure and the characteristic appearance of the constituents observed in this series are shown in Plate 1 and are discussed under the heading, "Discussion of results."

AGING TESTS.

The results of the one month aging test are included in Table 1. The remainder of the specimens are on file in the metals branch, to be pulled at later dates.

DISCUSSION OF RESULTS.

Figure 1 indicates that the useful range of magnesium in the copper-zinc-aluminum alloys is limited to 0.25 to 1 per cent. (Alloys containing more than 1 per cent magnesium were too brittle to obtain reliable or consistent tension test results.)

Figure 2 shows that the highest elongation of the alloys investigated is less than 2 per cent, which is very low when compared to the alloys containing iron in place of magnesium. In the former alloys an elongation of 5 per cent is regularly obtained in routine practice, while as high as 8 per cent was obtained in the experimental melts. Even though the tensile strength is about the same, this lack of ductility precludes the use of magnesium in place of iron in aluminum alloy No. 3, Specification No. 11019. By heat treatment the tensile strength of the alloys containing magnesium in the limits specified above may be considerably increased. The elongation is either not affected or slightly decreased.

The hardness values of the magnesium series in both the "as cast" and heat treated conditions are considerably above those obtained for the iron alloy.

The high temperature tests show that magnesium does not increase the usefulness of the alloy under Specification No. 11019 for parts subjected to high temperatures.

The hot shortness and shrinkage results are on the same order as those obtained for aluminum alloy No. 3.

EXPLORATORY MELTS.

The exploratory melts are not of special interest. The addition of silicon to alloys containing more than 1 per cent magnesium slightly increases the tensile strength and malleability. Tellurium has practically no effect on the physical properties when added to a 3 per cent magnesium alloy of this series.

Magnesium first appears as a blue constituent, which is shown in Plate 1, Figures 1 and 2. This corresponds to the constituent which has been identified by British workers (Ref. Eleventh Report of the Alloy Research Committee) as Mg_2Si. In the alloys containing less than 1 per cent of magnesium it occurs in very small globules.

With more than 1 per cent of magnesium, the globules increase in size and in quantity and often have a mottled appearance with black edges. It was also observed that this constituent occurs intimately mixed with the $CuAl_2$ and suggests a ternary eutectic. Hanson and Gayler (Ref. Institute of Metals (British), Vol. XXVI, pp. 321–359, inclusive) have attributed the aging effect of duralumin to this constituent. In the copper-zinc-magnesium aluminum alloys, no difference either in the amount or the form of the Mg_2Si was observed in the "as cast" and heat treated conditions. Some of the copper and all of the zinc enter into solid solution with the aluminum and undoubtedly affect the solubility of the magnesium compounds and may alter the limits given by Hanson. It was found that the $CuAl_2$, visible in the "as cast" specimens, readily goes into solution when subjected to the heat treatments.

Between 1 and 2 per cent added magnesium, a constituent corresponding to Al_2Mg_3, as described by Hanson (Institute of Metals (British), Vol. XX, p. 201), makes its appearance. This constituent is shown in Plate 1, Figure 4. It is readily attacked by dilute solutions of nitric acid of either alcohol or water. In the unetched specimen it is only faintly visible, but is colored black by a 10 per cent solution of nitric acid in alcohol. The appearance of this constituent corresponds to the maximums on the tensile strength and elongation curves in Figures 1 and 2.

In the furnace-cooled specimens containing over 1 per cent magnesium a precipitate of globules and needles which were too faint to be resolved at 500 diameters was observed throughout the matrix. At 1,000 diameters, however, these particles appeared similar to the larger areas of Al_2Mg_3 and reacted in the same manner when etched with 10 per cent alcoholic nitric acid solution. In this respect it is interesting to note that the hardness values of these furnace-cooled alloys rapidly decrease with an increase in the magnesium content, while with the alloys in the cast condition, heat treated, and quenched, show an increase in hardness.

A slate gray constituent with a purple tinge was observed throughout this series, the amount of which was neither affected by the magnesium content nor the various heat treatments. This resembles what is thought to be the iron-silicon compound which has been observed in practically all of the alloys of aluminum and is described in Material Section Report No. 178, Serial No. 1964, Air Service Information Circular, Vol. IV, No. 385. It is shown in the half-tone areas of Figures 1 and 2, Plate 1. Figure 3 shows needles of a similarly colored constituent whose shape indicates $FeAl_3$, which is also described in the report just mentioned. These needles were observed principally in the exploratory melts containing added silicon.

TABLE 1.

Alloy symbol.	Number of bars.	(1)	Tensile strength (pounds per square inch).	Elongation in 2 inches, (per cent).	Brinell.	Rockwell.	Scleroscope.	Specific gravity.	Shrinkage (inches per foot).
M-¼	6	A	24,960	1.40	60	52	16	2.87	0.1087
	3	B	26,140	2.00	57	53	19	......	
	3	C	23,760	1.17	70	52	23	2.86	
	3	D	29,700	1.5	70	55	29	2.85	
	3	E	27,660	1.17	77	61	27	2.87	
	3	F	35,800	1.5	83	65	33	2.88	
	3	G	34,220	2.0	80	63	28	2.86	
M-½	6	A	27,330	1.40	65	50	19	2.87	0.1049
	3	B	26,390	1.80	63	54	17	2.86	
	3	C	25,310	1.00	70	53	18	2.85	
	3	D	28,440	1.50	67	57	25	2.85	
	3	E	31,120	1.00	74	60	28	2.87	
	3	F	31,670	1.17	77	62	29	2.86	
	3	G	35,680	.83	80	62	31	2.86	
M-1	6	A	21,935	1.35	72	56	19	2.85	0.0975
	3	......	22,160	.83	77	65	30	2.85	
	3	C	20,910	1.0	74	61	21	2.84	
	3	D	23,860	1.5	74	64	27	2.82	
	3	E	21,390	.67	63	54	22	......	
	3	F	22,160	.83	77	65	30	2.85	
	3	G	35,590	.67	86	68	35	......	
M-2	6	A	11,415	.50	83	61	21	2.84	0.0833
	3	B	16,590	.50	80	61	20	2.86	
	3	D	13,520	1.0	96	67	35	2.83	
	3	E	11,630	.67	48	34	13	2.80	
	2	F	12,130	.50	91	67	37	2.83	
	3	G	15,330	.5	100	74	45	2.80	
M-3	3	A	10,890	.5	93	63	26	2.82	0.0831
	......	B	8,790	.3	93	66	26	2.76	
	......	C	12,380	.5	93	70	40	2.84	
	......	E	5,950	.5	38	23	11	2.66	
	......	G	1,050	......	119	77	54	2.79	
M-4½	3	A	8,790	.3	93	66	26	2.76	
	3	G	4,500	......	100	73	54	2.67	
M2-S4	3	A	21,150	.5	86	62	19	2.80	
	3	E	19,950	1.0	86	48	31	2.78	
	3	G	28,400	.5	93	68	36	2.83	
M.5-S.5	3	A	25,475	.5	73	54	18	2.81	
	3	E	28,200	1.0	73	59	24	2.87	
	3	F	33,120	.83	86	65	34	2.85	
	3	G	33,540	.83	80	64	31	2.86	
M3-T2	......	A	15,250	.50	86	61	22	2.85	
	3	......	9,400	.67	96	68	35	2.86	

[1] A. "As cast" condition.
B. "As cast." Remelt of A.
C. Same as A. Machined.
D. Same as B. Aged one month.
E. Three hours at 920°F. Furnace cooled.
F. Three hours at 920°F. H_2O, 70°F.
G. Three hours at 920°F. Quench, H_2O, 212°F. Aged three hours at 212°F.

TABLE 2.

Alloy symbols.	Melt No.	Composition as mixed.						Chemical analysis. [1]					
		Mg.	Cu.	Zn.	Al.	Si.	Te.	Mg.	Cu.	Zn.	Fe.	Si.	Al.
M-¼	1428	0.25	2.00	10.00	87.75	....	....	0.53	2.10	10.58	0.47	0.31	86.01
M-½	1434	.50	2.00	10.00	87.50	....	....	.59	2.06	10.18	.46	.30	86.41
M-1	1438	1.00	2.00	10.00	87.00	....	....	1.03	1.95	9.96	.60	.30	86.16
M-2	1447	2.00	2.00	10.00	86.00	....	....	1.65	2.06	9.67	.44	.23	85.95
M-3	1453	3.00	2.00	10.00	85.00	....	....	1.70	2.18	9.46	.44	.23	85.99
M-4½	1455	4.50	2.00	10.00	83.50	....	....	....	....	....	....	....	....
M2-S4	1456	2.00	2.00	10.00	82.00	4.00	....	....	....	....	....	....	....
M.5-S.5	1472	.50	2.00	10.00	87.00	.50	....	....	....	....	....	....	....
M3-T2	1460	3.00	2.00	10.00	83.00	....	2.00	....	....	....	....	....	....

[1] Not determined for melt Nos. 1455, 1456, 1472, and 1460.

ADDENDUM.

PHYSICAL PROPERTIES AFTER SIX MONTHS' AGING.

Melt No.	1433	1433	1433	Average.	1436	1436	1436	Average.
Chemical composition	Cu 2; Zn 10; Mg .25; Al. bal.				Cu 2; Zn 10; Mg .5; Al. bal.			
Specimen No	4-A	4-B	4-C		6-A	6-B	6-C	
Type of specimen	Cast round.				Cast round.			
Diameter, inches	0.502	0.504	0.494		0.493	0.502	0.500	
Ultimate strength (pounds per square inch)	27,740	21,800	23,900	24,480	27,760	31,430	30,200	29.800
Elongation, per cent in 2 inches	0.5	0.5	0.5	0.5	0.5	1.0	1.0	0,83
Location of fracture	O T	O T	O T		O T	O T	O T	O
Character of fracture	Coarse-granular.				Coarse-granular.			

Melt No.	1440	1440	1440	Average.	1449	1449	1449	Average.
Chemical composition	Cu 2; Zn 10; Mg 1.0; Al. bal.				Cu 2; Zn 10; Mg 2.0; Al. bal.			
Specimen No	6-A	6-B	6-C		6-A	6-B		
Type of specimen	Cast round.				Cast round.			
Diameter, inches	0.503	0.502	0.493		0.502	0.503	....	
Ultimate strength (pounds per square inch)	21,250	21,320	25,620	22,730	13,290	16,560	....	14,925
Elongation, per cent in 2 inches	1.0	1.0	0.5	0.83	....	....	....	
Location of fracture	O T	M T	O T	....	O T	O T	....	
Character of fracture	Coarse-granular.				Coarse-granular.			

Melt No.	1457	1457	1457	Average.
Chemical composition	Cu 2; Zn. 10; Mg. 3; Al. balance.			
Specimen No	10-A	10-B	10-C	
Type of specimen	Cast round.			
Diameter, inches	0.496	0.508	0.503	
Ultimate strength (pounds per square inch)	14,490	7,840	10,520	10,950
Elongation, per cent in 2 inches	0.50	0 50	0.50	0.50
Location of fracture	O T	M T	O T	
Character of fracture	Coarse-granular.			

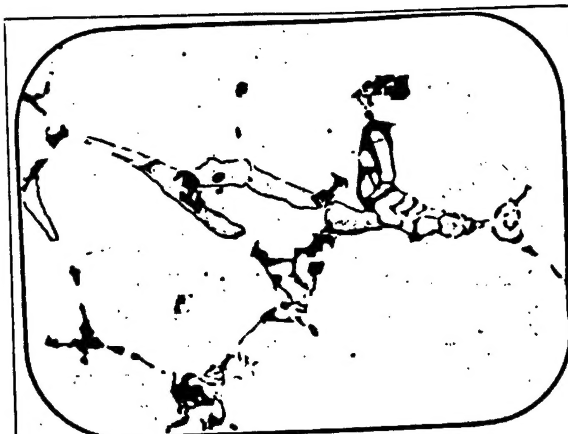

Fig. 1. 1000 X. Unetched.
Black - Mg_2Si
Light - $CuAl_2$
Half tone - probably X constituent.

Fig. 2. 1000 X. Etch 10 per cent Solution HNO_3 in Alcohol
Black - Al_2Mg_3
Half tone - probably X constituent.

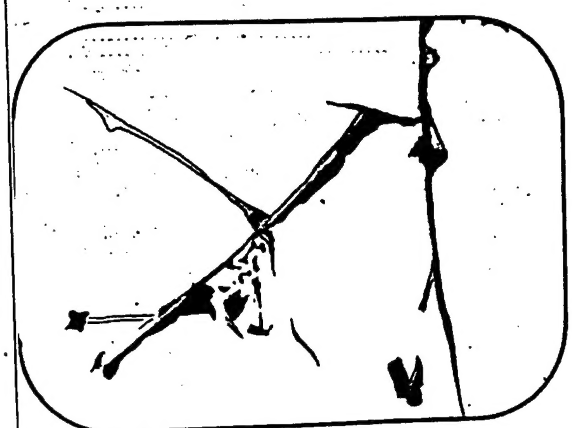

Fig. 3. 1000 X. Unetched.
Black - Mg_2Si
Light - $CuAl_2$
Half tone - probably needles $FeAl_3$.

Fig. 4 - 1000 X. Etch 10 per cent Solution HNO_3 in Alcohol
Precipitate in furnace-cooled specimens (Black) which resembled Al_2Mg_3.

Plate 1.

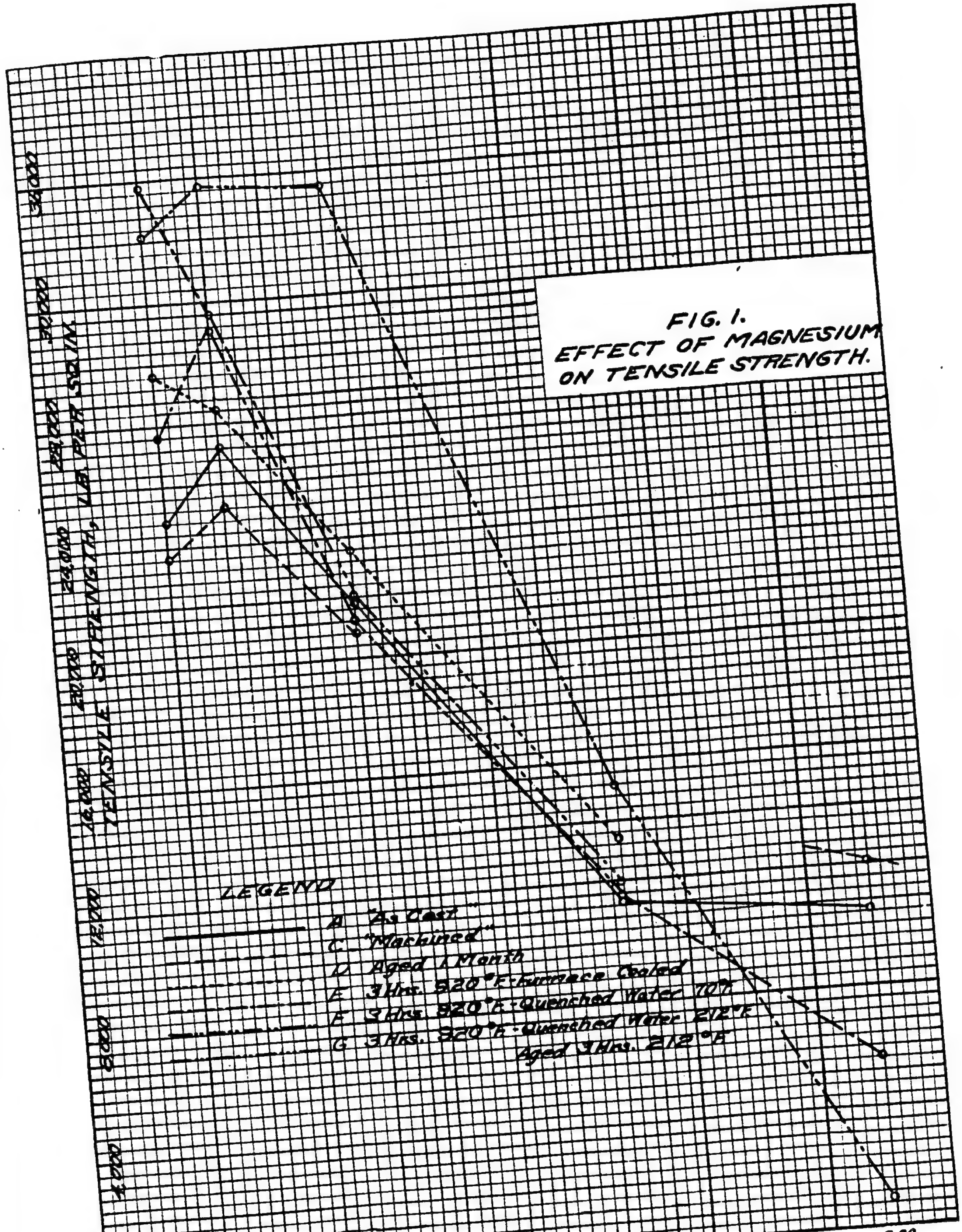

FIG. 1.
EFFECT OF MAGNESIUM ON TENSILE STRENGTH.

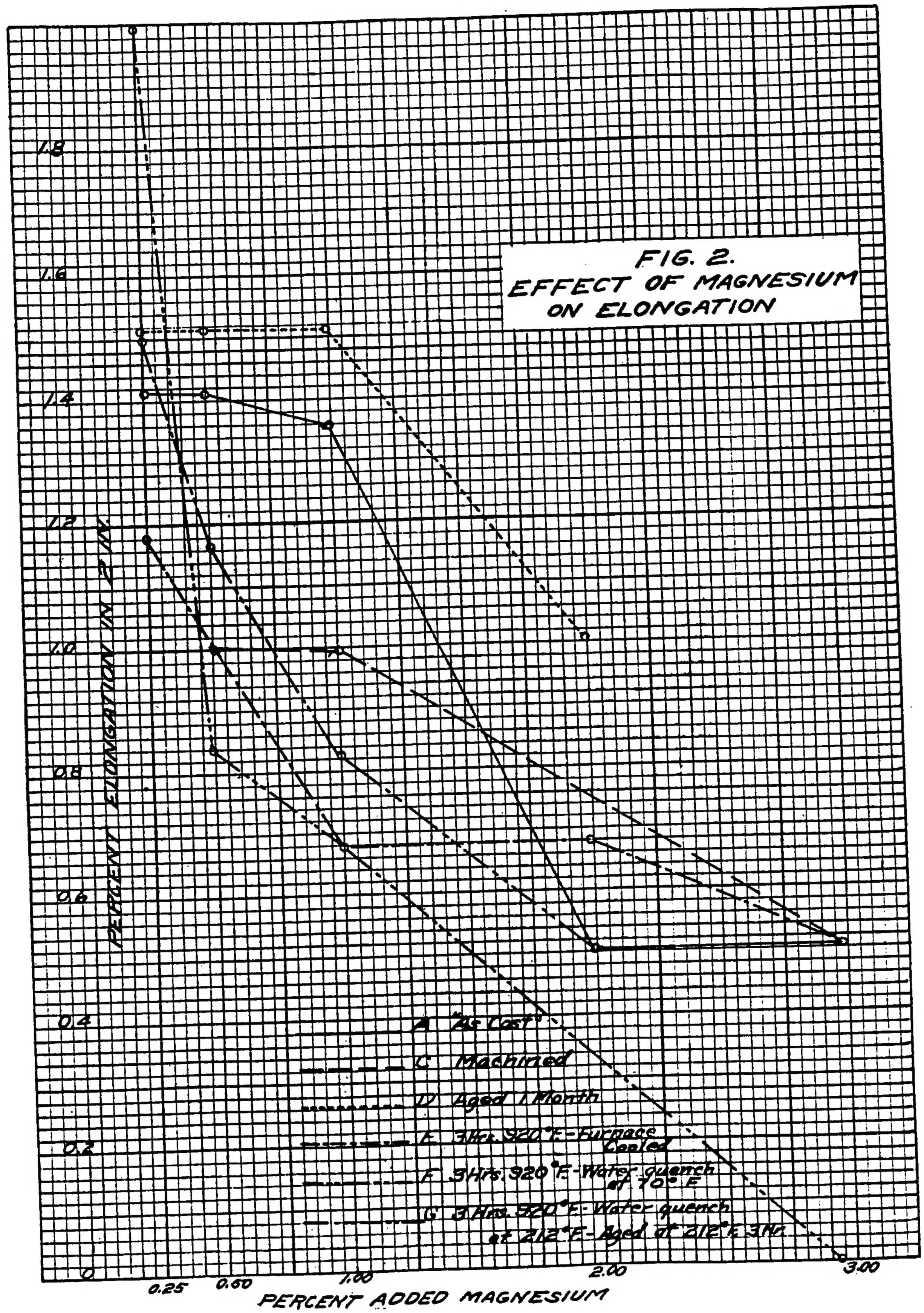

FIG. 2.
EFFECT OF MAGNESIUM ON ELONGATION

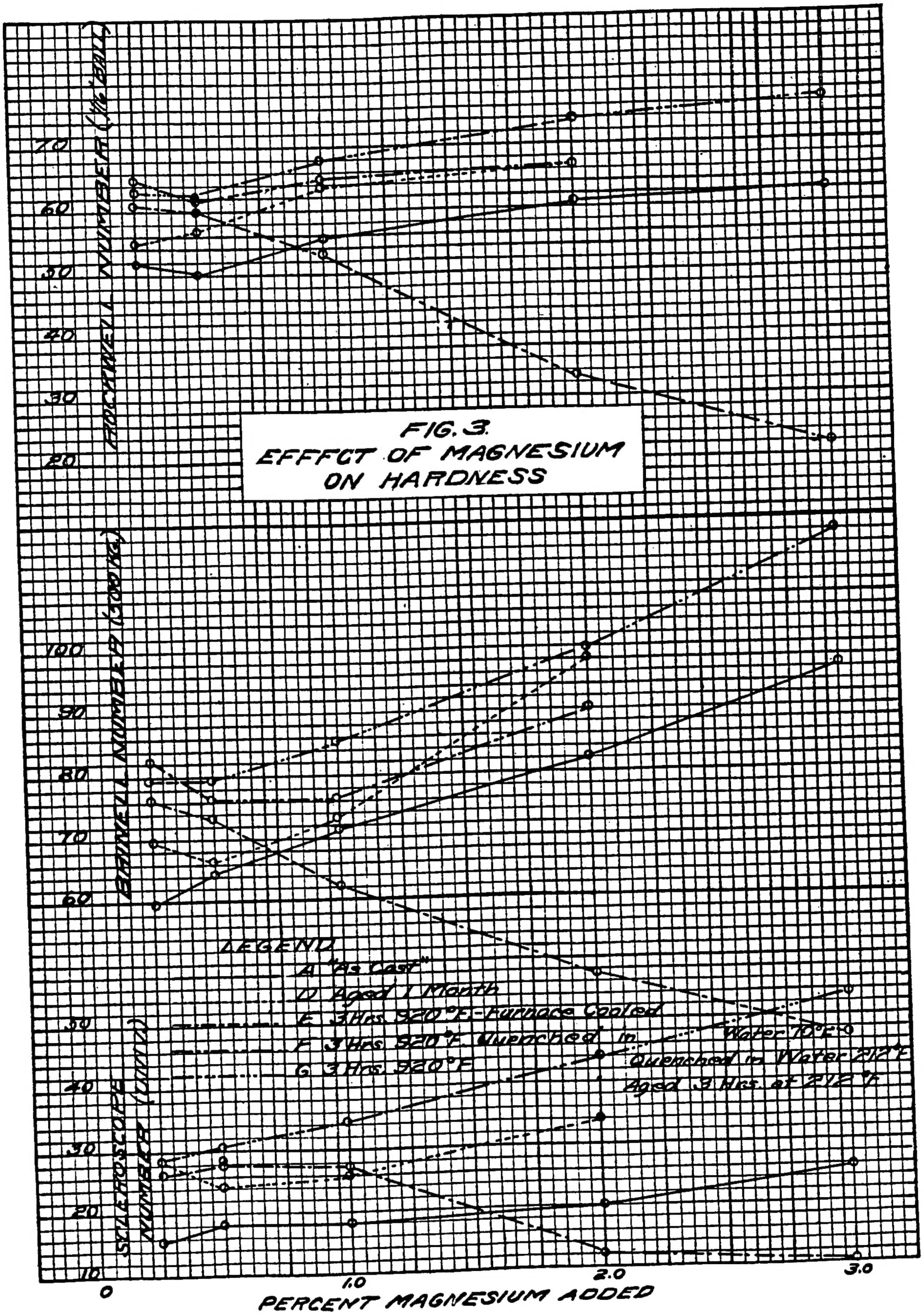
FIG. 3
EFFECT OF MAGNESIUM ON HARDNESS
ROCKWELL NUMBER (1/16" BALL)
BRINELL NUMBER (500 Kg.)
SCLEROSCOPE NUMBER (UNITS)
LEGEND
A "As Cast"
D Aged 1 Month
E 3 Hrs. 920°F. Furnace Cooled
F 3 Hrs. 920°F. Quenched in Water 70°F.
G 3 Hrs. 920°F. Quenched in Water 212°F. Aged 3 Hrs. at 212°F.
PERCENT MAGNESIUM ADDED
0
1.0
2.0
3.0

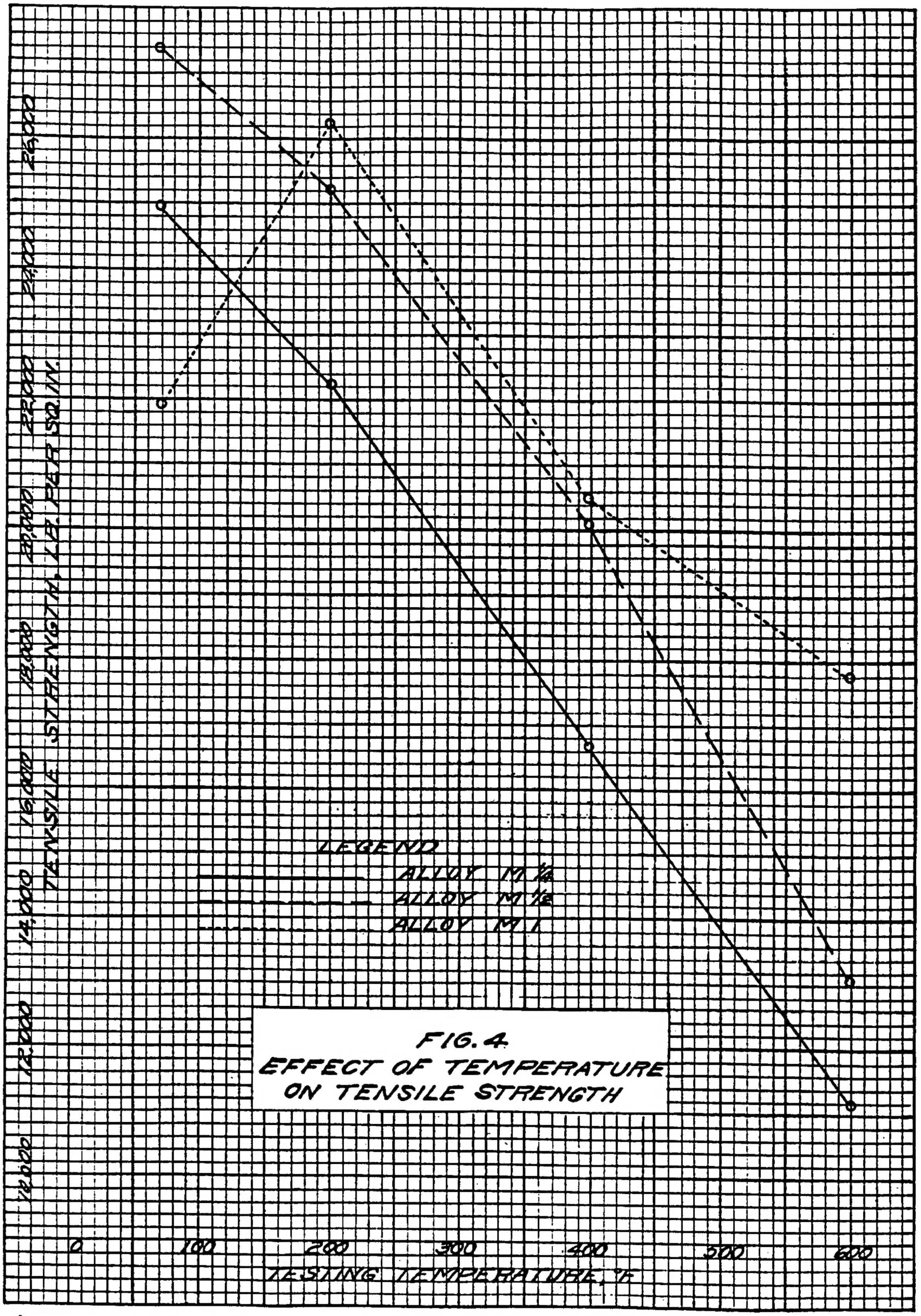

FIG. 4
EFFECT OF TEMPERATURE ON TENSILE STRENGTH

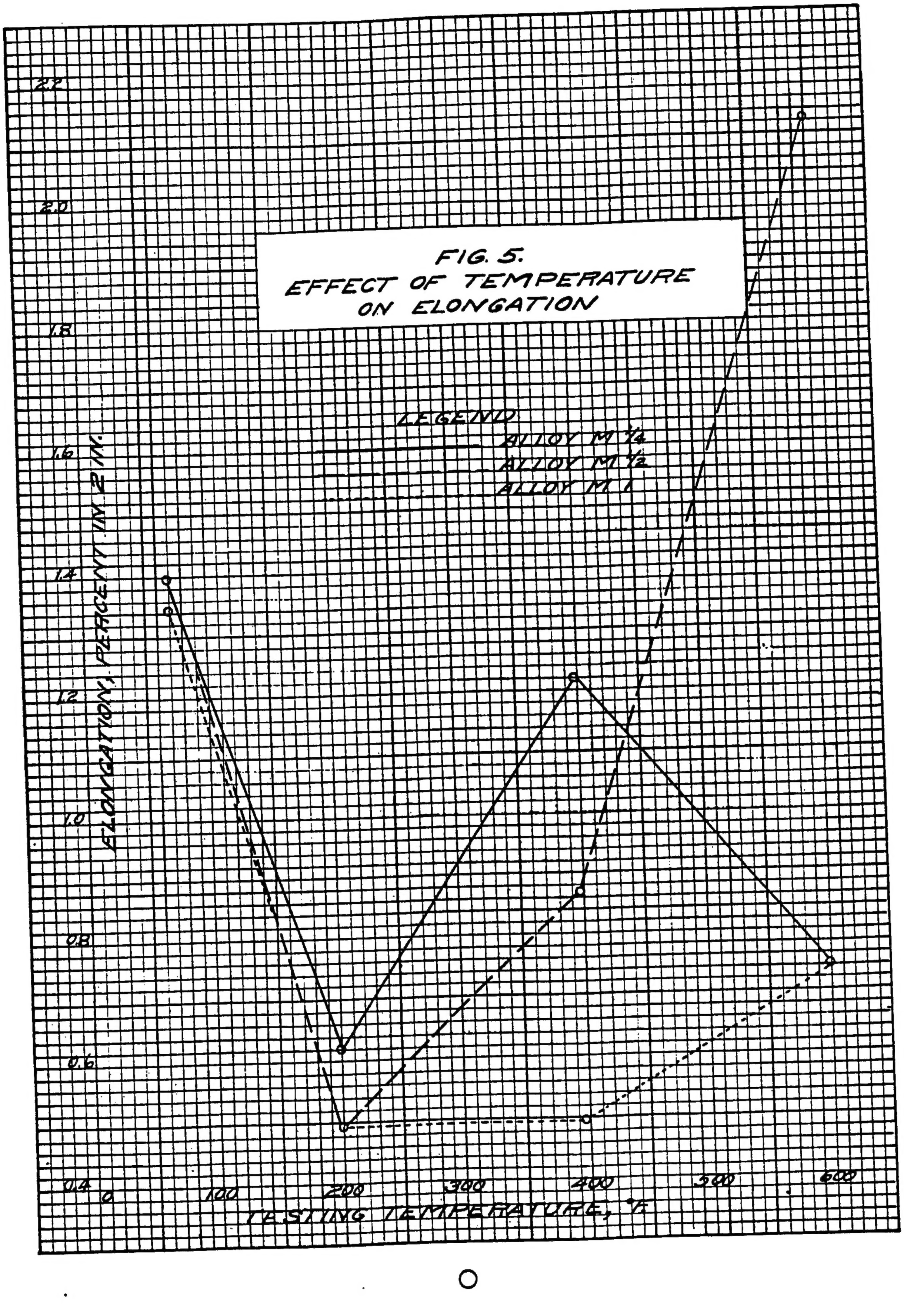
FIG. 5.
EFFECT OF TEMPERATURE
ON ELONGATION
LEGEND
ALLOY M 1/4
ALLOY M 1/2
ALLOY M 1
ELONGATION, PERCENT IN 2 IN.
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0
100
200
300
400
500
600
TESTING TEMPERATURE, °F.